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DIELECTRIC PARAMETERS RECOGNITION BY USING A WAVEGUIDE CAVITY AND A RIGOROUS PROCESSING ALGORITHM

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INTRODUCTION

Measurement of scattered electromagnetic field and further permittivity or permeability reconstruction based on experimental data and adequate mathematical model is the key issue in dielectric materials study [1, 2]. Here, accuracy of measurements and adequacy of mathematical model is of principal importance. Today, special attention is attracted to the study of thin dielectric films with $tg(\delta) \sim 10^{-3} \div 10^{-6}$. In this paper we consider a resonator that can be used for a thin film study, its electromagnetic model, and advantages and capacities of corresponding numerical algorithm.
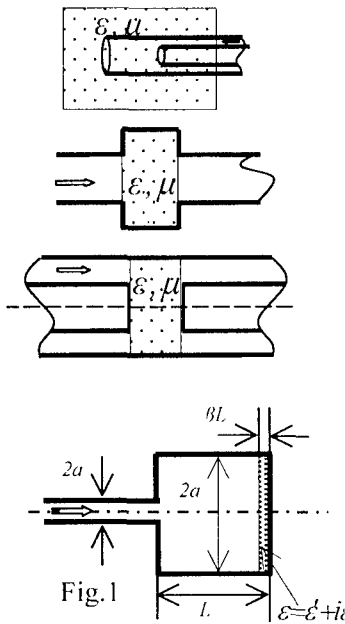

Fig.1

DESCRIPTION OF THE ALGORITHM

Our solution to inverse problem is based on accurate and efficient solution to direct problem. Suppose that the diffraction of one of the modes of small circular waveguide by the chamber (Fig.1) is reduced to a functional relation $Y = f(X)$. Here $X = (x_1, x_2, x_3 \dots x_m)$ is the set of input data (frequency, ε, geometry, amplitude of incident wave A, etc.) and $Y = (y_1, y_2, \dots, y_n)$ is the set of output data - reflection coefficients $R_1, R_2, \dots R_n$, normalized by A. Assume that a part of input data is known (frequency and geometry) and given by the values $x_1^0, x_2^0, \dots x_l^0$ $(l < m)$ from the set X of all input variables. Suppose also that values $Y^0 = (y_1^0, y_2^0, \dots y_n^0)$ of output variables are known. The problem of the model identification is reduced to a necessity of finding $x_{l+1}, \dots x_m$ from equation

$$Y^0 = f(x_1^0, \dots x_l^0, x_{l+1}, \dots x_m) \qquad (1)$$

In our case, we have to find unknown dielectric constant $\varepsilon = \varepsilon' + i\varepsilon''$. The accuracy of the parameter evaluation depends on several factors:

1. The error of reproduction of the relation between output data Y, known input data $x_1, x_2, x_3 \dots, x_m$, and unknown parameters in the form of equation (1), that is called inadequacy of the model to the phenomena simulated.

2. Errors of measuring the known parameter values, that is Y^0, $x_1^0, x_2^0, \dots x_l^0$.

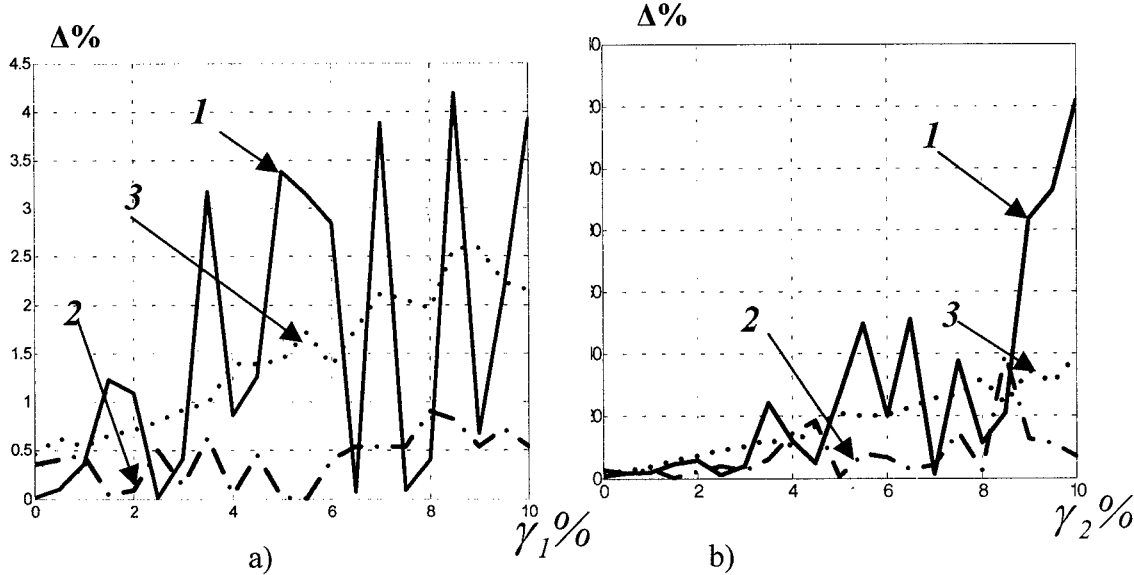3. Errors of the numerical algorithm applied to solving equation (1).

Fig.2

As a functional relation we choose the solution of the considered problem obtained by the semi-inversion method [4, 6]. Here, we reduce it to numerical solution of a matrix equation of the second kind $R^M - HR^M = B$ with exponential convergence. This approach allows us to find out with given accuracy the amplitudes of reflected modes $R_1^M, R_2^M, ..., R_N^M$ if the frequency, geometry, and dielectric constant $\varepsilon = \varepsilon' + i\varepsilon''$ are known, so that $R_n^M = f_n(\kappa, \varepsilon, A)$ depends on geometry, frequency parameter $\kappa = a/\lambda$ (a is characteristic dimension, see Fig.1), and ε. The accuracy of calculation of R_n is limited by the capacity of the computer utilized. For the solution of direct and inverse problems we used the ideas of [7, 3-5]. We pose the inverse problem as a minimization one, see [6,3,4]. After caring out numerical investigation of various types of functionals according the scheme of [4], we arrive at the conclusion that the most efficient is

$$\Phi(\varepsilon) = \sum_{m=1}^{P} \sum_{n=1}^{N} F\left(R_{nm}^e - R_n^M(\kappa_m, \varepsilon)\right) + \alpha \Omega(\varepsilon) \tag{2}$$

where $F(u) = |u|^2$. Due to analyticity of functions $R_n^M(\kappa, \varepsilon, A)$ in κ and ε, the functional in (2) (within the considered level of input errors) does not require regularization and we can put (2) $\alpha = 0$.

NUMERICAL EXPERIMENTS

In the parameter reconstruction of thin films, $\beta L < \lambda$, with small $tg(\delta)$ there are two most important criteria:
-   influence of the error of input data on the accuracy of parameter reconstruction, and
-   range of parameters, within which accuracy ofed by the algorithm is sufficient.

To simulate experimental input data we used (see also [3, 4]) a generator of random numbers with normal distribution:

$$R_n^e(\kappa, \varepsilon) = \left|R_n^M(\kappa, \varepsilon)(1 + \gamma_1 Random)exp\left(arg\left(R_n^M(\kappa, \varepsilon)\right)(1 + \gamma_2 Random)\right),$$

where $-1 < Random < 1$. We studied the relative errors of reconstructed parameters and algorithm properties according to the formulas:

$$\Delta_{tg} = \frac{|tg(\delta)_R - tg(\delta)_M|}{tg(\delta)_M}\ \%; \quad \Delta_\varepsilon = \frac{|\varepsilon_R' - \varepsilon_M'|}{\varepsilon_M'}\ \%;\ \text{and}\quad \Delta = \left(\frac{\sum_j R_n^c(\kappa_j) - R_n^M(\varepsilon_R,\kappa_j)^2}{\sum_j R_n^c(\kappa_j)^2}\right)^{1/2}$$

as functions of input data errors. Relevant curves are marked as 1,2,3 in Fig.2, respectively. In all experiments we accounted 21 frequency points in functional (2).

Fig. 2 presents the variations of relative errors when input data errors for amplitudes γ_1 and arguments γ_2 change from 0% to 10%. In Fig.2-a we fixed $\gamma_2 = 3\%$ and in Fig.2-b it was $\gamma_1 = 5\%$. Here we had to present curves 2 corresponding to the values of $\Delta_\varepsilon \cdot 100$ in order to be visible within the common scale. The errors change randomly, however around certain increasing with rise of errors level mean values. The input errors in arguments influence the accuracy more crucially, and it is clear that better to accept errors less than 5%. Due to the high accuracy of the algorithm of direct problem solution, there is no restriction on reconstructed parameters if one has "hypothetical" situation with accurate input data, i.e. if $\gamma_1 = \gamma_2 = 0$. However, from numerical experiments we conclude that if the error in input data is $\gamma_1 \geq 10\%$ (for normalized amplitude that is deviation of 0.1) and $\gamma_2 \geq 5\%$ (that is 18°) it is necessary to apply regularization to (2).

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